

# NY Serpentis: SU UMa-Type Nova in the Period Gap with Diversity of Normal Outbursts

Elena P. PAVLENKO,<sup>1\*,2</sup> Taichi KATO,<sup>2</sup> Oksana I. ANTONYUK,<sup>1</sup> Tomohito OHSHIMA,<sup>2</sup>  
 Franz-Josef HAMBSCH,<sup>3,4,5</sup> Kirill A. ANTONYUK,<sup>1</sup> Aleksei A. SOSNOVSKIY,<sup>1</sup>  
 Alex V. BAKLANOV,<sup>1</sup> Sergey Yu. SHUGAROV,<sup>6,7</sup> Nikolaj V. PIT,<sup>1</sup> Chikako NAKATA,<sup>2</sup>  
 Gianluca MASI,<sup>8</sup> Kazuhiro NAKAJIMA,<sup>9</sup> Hiroyuki MAEHARA,<sup>10</sup> Pavol A. DUBOVSKY,<sup>11</sup>  
 Igor KUDZEJ,<sup>11</sup> Maksim V. ANDREEV,<sup>12,13</sup> Yuliana G. KUZNYETSOVA,<sup>14</sup>  
 Kirill A. VASILISKOV,<sup>15</sup>

<sup>1</sup> *Crimean Astrophysical Observatory, 98409, Nauchny 19/17, Crimea, Ukraine*

<sup>2</sup> *Department of Astronomy, Kyoto University, Kyoto 606-8502*

*\*eppavlenko@gmail.com*

<sup>3</sup> *Groupe Européen d'Observations Stellaires (GEOS), 23 Parc de Levesville, 28300 Bailleau  
 l'Evêque, France*

<sup>4</sup> *Bundesdeutsche Arbeitsgemeinschaft für Veränderliche Sterne (BAV), Munsterdamm 90, 12169  
 Berlin, Germany*

<sup>5</sup> *Vereniging Voor Sterrenkunde (VVS), Oude Bleken 12, 2400 Mol, Belgium*

<sup>6</sup> *Sternberg Astronomical Institute, Lomonosov Moscow University, Universitetsky Ave., 13, Moscow  
 119992, Russia*

<sup>7</sup> *Astronomical Institute of the Slovak Academy of Sciences, 05960, Tatranska Lomnica, the Slovak  
 Republic*

<sup>8</sup> *The Virtual Telescope Project, Via Madonna del Loco 47, 03023 Ceccano (FR), Italy*

<sup>9</sup> *Variable Star Observers League in Japan (VSOLJ), 124 Isatotyo, Teradani, Kumano, Mie 519-4673*

<sup>10</sup> *Kiso Observatory, Institute of Astronomy, School of Science, The University of Tokyo 10762-30,  
 Mitake, Kiso-machi, Kiso-gun, Nagano 397-0101*

<sup>11</sup> *Vihorlat Observatory, Mierova 4, Humenne, Slovakia*

<sup>12</sup> *Institute of Astronomy, Russian Academy of Sciences, 361605 Peak Terskol, Kabardino-Balkaria,  
 Russia*

<sup>13</sup> *International Center for Astronomical, Medical and Ecological Research of NASU, Ukraine 27  
 Akademika Zabolotnoho Str. 03680 Kyiv, Ukraine*

<sup>14</sup> *Main Astronomical Observatory of NASU, Ukraine 27 Akademika Zabolotnoho Str. 03680 Kyiv,  
 Ukraine*

<sup>15</sup> *Taras Shevchenko National University, Kyiv 022, prosp. Glushkova 2, Ukraine*

(Received 201 0; accepted 201 0)

## Abstract

We present photometric study of NY Ser, an in-the-gap SU UMa-type nova, in 2002 and 2013. We determined the duration of the superoutburst and the mean superhump period to be 18 d and 0.10458 d, respectively. We detected in 2013 that NY Ser showed two distinct states separated by the superoutburst. A state of rather infrequent normal outbursts lasted at least 44 d before the superoutburst and a state of frequent outbursts started immediately after the superoutburst and lasted at least for 34 d. Unlike a typical SU UMa star with bimodal distribution of the outbursts duration, NY Ser displayed a diversity of normal outbursts. In the state of infrequent outbursts, we detected a wide  $\sim 12$  d outburst accompanied by 0.098 d orbital modulation but without superhumps ever established in NY Ser. We classified this as the “wide normal outburst”. The orbital period dominated both in quiescence and during normal outbursts in this state. In the state of the most frequent normal outbursts, the 0.10465 d positive superhumps dominated and co-existed with the orbital modulation. In 2002 we detected the normal outburst of “intermediate” 5–6 d duration that was also accompanied by orbital modulations.

**Key words:** accretion, accretion disks — stars: novae, cataclysmic variables — stars: dwarf novae — stars: individual (NY Serpentis)

## 1. Introduction

Cataclysmic variables (CVs) are close binary stars at the late stage of their evolution (Warner 1995; Hellier 2001 for reviews). In these binaries the late-type star fills in its Roche lobe and transfers matter onto the compact component (white dwarf) through an accretion disk. The thermal-viscous instability in the accretion disk causes outbursts (Cannizzo 1993; Lasota 2001).

The SU UMa-type stars are a subgroup of the short-periodic non-magnetic cataclysmic variables occupying a region of the orbital periods bounded by the minimum period at  $\sim 76$  min and the upper limit of the “period gap”, 3.18 hr (Knigge 2006). SU UMa stars show the well-known bimodality of the outburst duration (van Paradijs 1983; Warner 1995): the narrow “normal” outbursts lasting for a few days and the wide superoutbursts that are longer in duration by a factor of 5–10 in the same system. Typical superoutburst lasts for about two weeks. Several normal outbursts occur between the superoutbursts. The amplitudes of superoutbursts are slightly higher than or equal to those of normal outbursts. van Paradijs (1983) pointed out that almost all dwarf novae have a bimodal distribution of the outburst duration. Only SU UMa stars, however, have the wide outbursts (superoutbursts) accompanied by what are called positive superhumps, which are brightness variations with periods a few percent longer than the orbital period.

According to the modern paradigm of the tidal instability, the 3:1 resonance in the accretion disk orbiting the white dwarf in systems with mass ratio  $q = m_2/m_1 \leq 0.25$ , where  $m_2$  is the mass of the late type star and  $m_1$  is that of the white dwarf, is responsible for its eccentric deformation, resulting in positive superhumps [Whitehurst (1988), Hirose, Osaki (1990), Lubow (1991)]. Osaki (1996) proposed a thermal-tidal instability model in which the ordinary thermal instability is coupled with the tidal instability.

The detailed study of the superoutbursts and evolution of the positive superhumps is given in the series of papers [Kato et al. (2009); Kato et al. (2010); Kato et al. (2012); Kato et al. (2013); Kato et al. (2014a); Kato et al. (2014b)]. The durations of superoutburst vary from one system to another, but is rather stable value for the same star (Warner 1995) in different occasions.<sup>1</sup>.

As for the durations of normal outbursts, they depend both on the orbital period and on the supercycle phase. It was found by the early investigations (van Paradijs 1983) that the duration of the narrow outburst  $t_b$  for several CVs increases with the orbital period. For the SU UMa stars, the empirical correlation between  $t_b$  and the orbital period was  $t_b \sim 2.5\text{--}5$  d. Recently Cannizzo et al. (2012) explored the Kepler light curves of the SU UMa stars V1504 Cyg and V344 Lyr and found a systematic increase of  $t_b$  between two consecutive superoutbursts, that were  $t_b=1.1\text{--}2.9$  d for V1504 Cyg and  $t_b=2.5\text{--}5.0$  d for V344 Lyr.

The 2.15–3.18 hr period gap (Knigge 2006) represents as division between the long-period systems with high mass-transfer rates (above the period gap) and short-period systems with low-mass transfer rates (below the period gap). The evolution of the long-period cataclysmic variables is mainly driven by magnetic braking, while the evolution of the short-period ones is driven by gravitational wave radiation [Kraft (1962), Verbunt, Zwaan (1981), Knigge (2006)]. According to the theoretical predictions, the secondary loses contact with its Roche lobe at an orbital period  $\sim 3$  hr and the secondary reaches contact again at an orbital period  $\sim 2$  hr. This causes the dearth of the CVs in this region of orbital periods, so this region is called the "period gap". Despite that a number of SU UMa-type stars in the period gap have grown with time [see, for example, Katysheva, Pavlenko (2003); Dai, Qian (2012); Schmidtobreick, Tappert (2006)], the properties of these systems are still poorly studied.

NY Ser is the first in-the-period gap SU UMa-type dwarf nova. It was discovered as an ultraviolet-excess object PG 1510+234 (Green et al. 1986; Green et al. 1982). Iida et al. (1995) identified that this object is a frequently outbursting dwarf nova. Nogami et al. (1998) detected superhumps during a long outburst in 1996 April, establishing the SU UMa-type classification. Its supercycle was estimated as 85–100 d in 1996 by Nogami et al. (1998) and 60–90 d according to Patterson et al. (2003), who observed mostly in 1999. NY Ser displayed rather frequent normal outbursts every 6–9 d [Nogami et al. (1998); Iida et al. (1995)] of durations about 3 d

---

<sup>1</sup> There are, however, exceptions especially in systems with low outburst frequencies. The notable example is BC UMa (Romano 1964). See also Kato (1995)

that are typical for the most of SU UMa-type dwarf novae. However the outburst activity of NY Ser in recent years differed from those of “normal” SU UMa-type stars. Using the AAVSO data, Kato et al. (2014a) found the existence of the outbursts with “intermediate” durations (about 4 d) that were observed in 2011–2012 in addition to normal outbursts with durations of  $\sim 3$  d and superoutburst with longer durations.

The period of positive superhump of NY Ser has been estimated by both Nogami et al. (1998) and Patterson et al. (2003). However, the details of the period evolution were not defined due to the insufficient amount of data. Only 3-d time series was obtained by Nogami et al. (1998) during the 1996 superoutburst and the 5-d one was obtained by Patterson et al. (2003) during the 1999 superoutburst. The analysis yielded the periods of 0.106 d and 0.104 d, respectively. This discrepancy of periods is probably because the superhump period was measured for different parts of the superoutburst between these two measurements.

Patterson et al. (2003) found the orbital period of 0.0975 d in quiescence and confirmed this value [0.09756(3) d] on the 8-d baseline covering both quiescence and outburst.

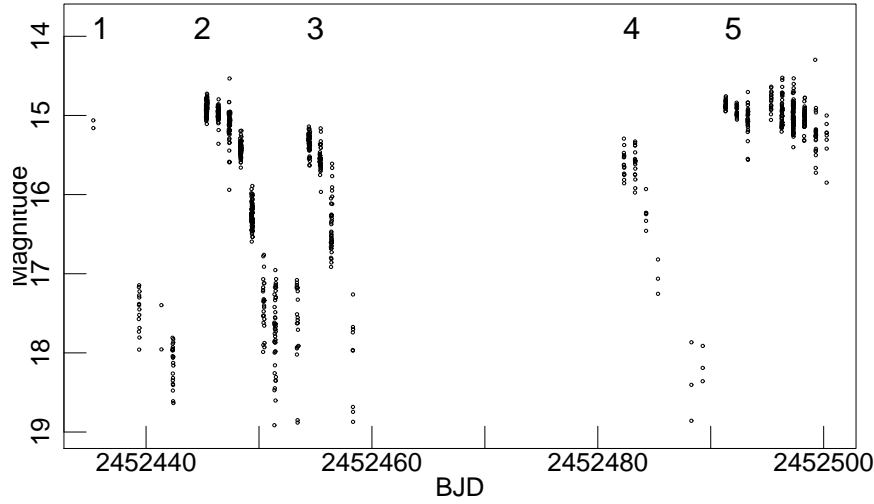
We undertook the photometric study of NY Ser to clarify the peculiarities of the outbursts and the behavior during the different phases of outburst activity.

## 2. Observations and data reduction

The photometric CCD observations of NY Ser have been carried out in 2002 and 2013. In 2002, the star was observed for a period of  $\sim 66$  d at the Crimean Astrophysical Observatory (CrAO) and in 2013 for a period of  $\sim 100$  d at several observatories located at different longitudes. The details of observations are given in the 2 available in electronic form only. The standard aperture photometry (de-biasing, dark subtraction and flat-fielding) was used for measuring of the variable and comparison star. The last one is the star USNO B1.0 1132-0246239. On 2006 July 07, we measured the brightness of the comparison star relative to the Landolt sequence stars 10971, having  $V = 11.493$ ,  $B - V = 0.323$ ,  $V - R = 0.186$  and 109381, having  $V = 11.73$ ,  $B - V = 0.704$ ,  $V - R = 0.428$ . We determined the magnitudes of the comparison star to be  $B = 16.48$ ,  $V = 15.92$ ,  $R = 15.56$  [Skiff (2007) gave  $V = 15.89$  and  $B - V = 0.58$ .]

Most of observations have been carried out without usage of filters, giving a system close to the  $R$  band in our case. The accuracy of a single brightness measure depended on the telescope, exposure time, weather condition and brightness of NY Ser. It was 0.007–0.03 mag during outburst and superoutburst and 0.05–0.10 mag in quiescence. The much higher accuracy about 0.005 mag during outbursts and 0.01 mag in quiescence was achieved in observations with the 2.6-m telescope.

The times of observations are expressed in Barycentric Julian Days (BJD). A phase dispersion minimization (PDM; Stellingwerf 1978) is used for period analysis, and  $1\sigma$  errors was estimated by the methods of Fernie (1989) and Kato et al. (2010). Before starting the period analysis, we corrected zero-point of data difference for different telescopes and subtracted a



**Fig. 1.** Overall light curve of NY Ser in 2002.

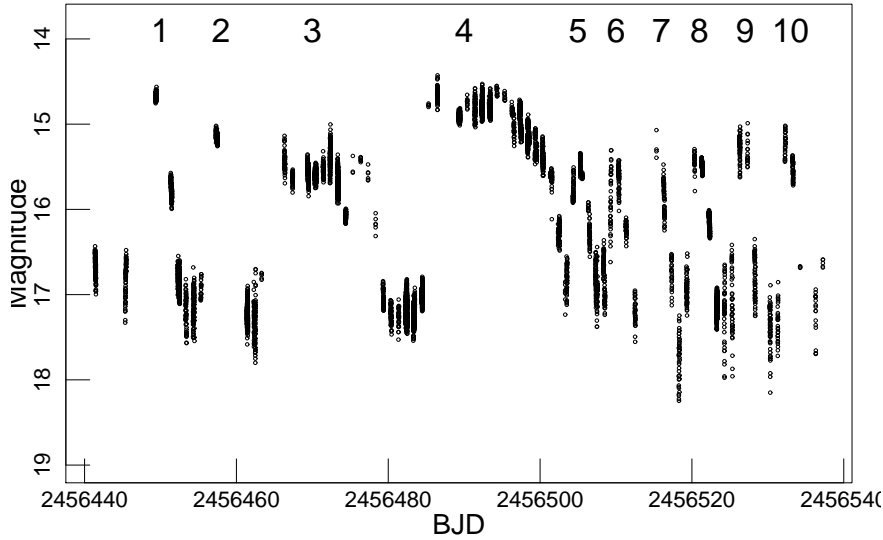
long-term trend of the outbursts and quiescent light curve by subtracting smoothed light curve obtained by locally-weighted polynomial regression (LOWESS, Cleveland 1979).

### 3. 2002 Light Curve

The observations of NY Ser carried out in 2002 are shown in figure 1. The 66-d light curve covered five outbursts of different duration that in average were separated by 9 d. While there is only indication to the first outburst, the next two outbursts were observed in better details. The second outburst was detected at BJD 2452445–2452450 and had duration at least 5 d (the possibility of 6 d also cannot be excluded). The third outburst occurred around BJD 2452455 and lasted for  $\sim 3$  d. The last two outbursts also were separated by  $\sim 9$  d in average. The outburst around BJD 2452485 has not been properly defined, but its duration was not shorter than 3 d. The next outburst started at BJD 2452490 and lasted at least for 11 d. In what follows, we call the second outburst in 2002, as the 2002 first wide outburst and the fifth one as the 2002 second wide outburst. The mean amplitude of both wide outbursts was about 2.5 mag.

### 4. 2013 light curve

The long-term light curve of NY Ser is presented in figure 2. This entire light curve consists of ten outbursts. Contrary to the “usual” SU UMa-type novae, having the sequences of short-term normal outbursts between superoutbursts, NY Ser demonstrated a large variety of outbursts during the 100-d interval. During the 44-d segment before BJD 2456464, the outburst behavior of NY Ser resembled its known behavior (Nogami et al. 1998; Patterson et al. 2003): the first and the second outbursts in figure 2 looked like the normal ones separated by  $\sim 8$  d



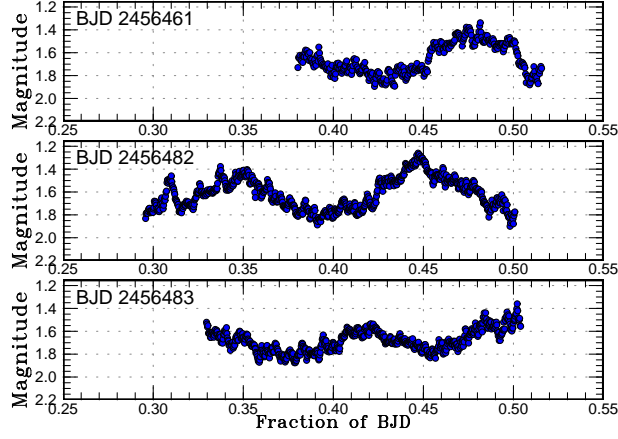
**Fig. 2.** Overall light curve of NY Ser in 2013.

and lasted for the 3–3.5 d. Their approximate amplitudes (about 2.5 mag) are consistent with the previously reported values. The third outburst in figure 2 that appeared approximately at the expected time was, however, entirely different. First, its duration was no shorter than 12 d but not longer than 15 d that never happened among the normal outbursts of the SU UMa-type stars, but is common for the duration of a superoutburst. Second, the mean amplitude of this outburst probably was less than those of the previous normal outbursts and did not exceed 1.8 mag. Third, the profile of this outburst looks rather symmetrical with a structured maximum lasting for at least 11 d. We call this the third outburst in 2013 as the 2013 first wide outburst below.

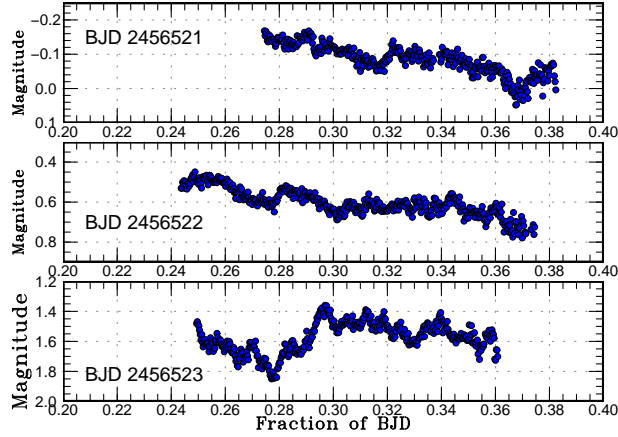
After the 5-d minimum following this outburst, the next wide outburst (the fourth outburst in 2013 and we call hereafter the 2013 second wide outburst) resembling a superoutburst was detected. Its amplitude was about 2.5 mag, the duration was 18 d, taking into account the precursor-like structure around BJD 2456485–2456487. Note also the prominent round shape of the maximum of this outburst. The slow decline lasted only for 6 d and occurred with a rate of  $\sim 0.12 \text{ mag d}^{-1}$ .

The sequence of six short outbursts with a mean amplitude of  $\sim 2$  mag has been observed immediately after the end of the longest outburst and this sequence lasted for 34 d. Their frequency of the outbursts changed dramatically: the separation between first two outbursts was only 5 d (that never was recorded before), the rest of the outbursts appeared every 6 d. Note that the amplitudes of the first two outbursts were also the smallest ones, reaching only 1.5 mag.

While the short outbursts have no doubt to be the “normal” outbursts according to the



**Fig. 3.** Example of the light curves for selected nights in 2013 quiescent state. The magnitudes are given relative to the comparison star.



**Fig. 4.** Example of the light curves for the declining branch of the normal outburst. The magnitudes are given relative to the comparison star.

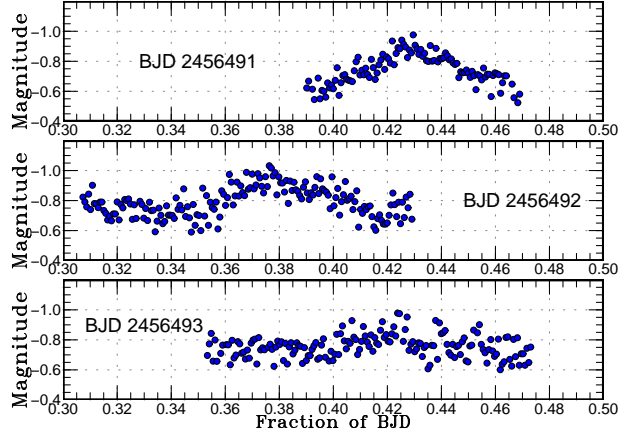
accepted definition of such outbursts in the SU UMa stars, the nature of two wide outbursts requires further study. We investigated short-term nightly periodicity (potential orbital and superhumps periods) to clarify the nature of these outbursts.

## 5. Short-Term Variability at Different States of the Dwarf Nova Activity

In all states of outburst activity in NY Ser, it displayed short-term brightness variations. Some examples of the nightly light curves are shown in figures 3, 4, 5.

We studied the periodicity of NY Ser for the two data sets at the selected states of its activity in a region of frequencies including the orbital and superhumps frequencies. The corresponding periodograms contain indication to the real signal and its one-day aliases. In the case of insufficient quantity and quality of the data, the formal probability of the real signal not always is higher than a false (aliased) one. So in all the periodograms we preferred those





**Fig. 5.** Example of the nightly light curves for the 2013 superoutburst. The magnitudes are given relative to the comparison star.

period as the real one that coincided or was close to the known periods ever observed in NY Ser.

#### 5.1. 2002 First Wide Outburst

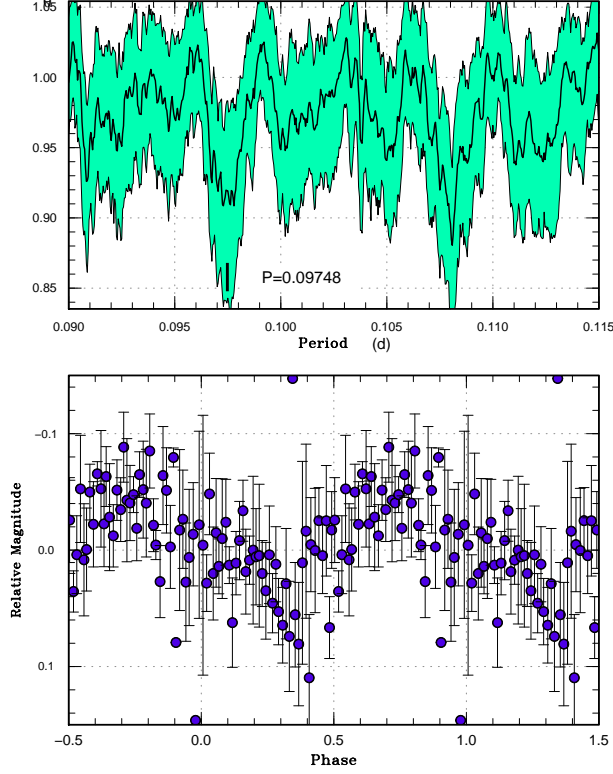
We selected the five light curves for the 2002 (BJD 2452445–2452449) first wide outburst. The corresponding PDM analysis for these data (the central part of the outburst) is presented in figure 6. For two of the most significant 1-day alias signals on the periodogram, one signal points to the 0.09748(17) d period that coincides with the orbital one within the limits of errors. The mean amplitude of the light curve is  $\sim 0.1$  mag. Its profile looks like a round maximum with some depression at phase 0.9 and with a sharp minimum. Note that 1-day alias signal points to the 0.108 d period and does not fall in the range between 0.104 d and 0.106 d that corresponds to the different estimates of the superhump period according to Nogami et al. (1998); Patterson et al. (2003).

#### 5.2. 2002 Second Wide Outburst

A PDM analysis for the data BJD 2452495–2452499 yielded a period which differs from the previous one (see figure 7). One of the 1-day aliased periods 0.10495(13) d, as in the case above, also falls in a range of the published superhump periods (Nogami et al. 1998; Patterson et al. 2003). Since the 1-day alias to the 0.10495(13) d period is far from the orbital one, so we accept the 0.10495(13) d period as the true one. The phase-averaged light curve is singly humped and has an amplitude  $\sim 0.2$  mag.

We identified that the first wide outburst having duration 5–6 d is a wide normal outburst, while the second one represents a fragment of a superoutburst, where the first three nights probably belong to the superoutburst precursor.





**Fig. 6.** Above: PDM analysis for the 2002 first wide outburst (BJD 2452445–2452448). The 90% confidence interval for  $\theta$  is shown by green strip. The preferable period is marked. Below: Phase-averaged profile of the data folded on the 0.09748 d period. For clarity data are reproduced twice.

### 5.3. 2013 First Wide Outburst

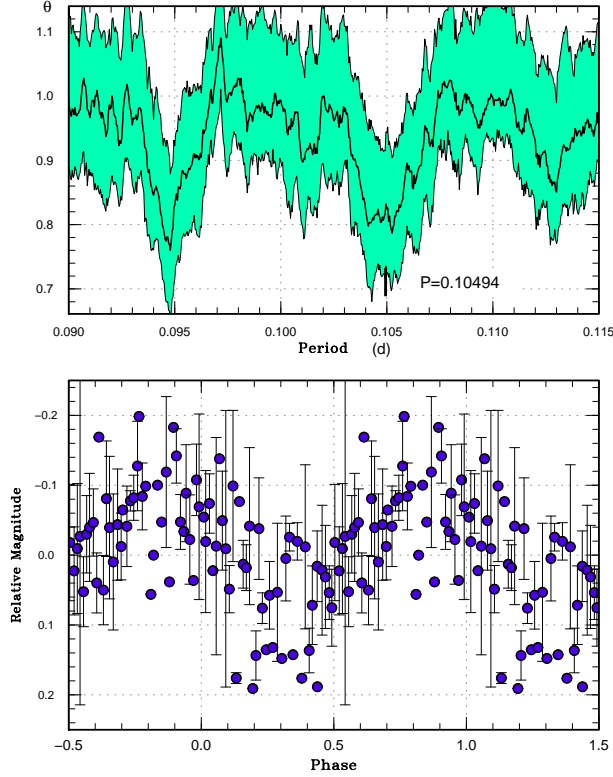
The periodogram obtained with PDM analysis for all of the data using the most densely observed part of this outburst (BJD 2456466–2456474) is shown in figure 8. Contrary to our expectation to detect superhumps for this wide outburst, the periodogram yield the only period of 0.09783(2) d that coincides with the orbital one. So we classified this outburst as the “wide normal outburst”.

### 5.4. 2013 Second Wide Outburst

We selected the data of 12 nights in a region of BJD 2456489–2456502 for the next wide outburst followed by the 5-d quiescence after the previous 12-d outburst, skipping the data of first two nights. The result of PDM analysis for detrended data is shown in figure 9.

The most significant signal points to the period of 0.104531(37) d. This period is close to the positive superhump period obtained for the 2002 superoutburst and to its evaluations reported by Nogami et al. (1998) and Patterson et al. (2003). The mean light curve obtained for this period has singly humped profile with  $\sim 0.1$  mag amplitude. This 18-d wide outburst is identified as a superoutburst.

Using the frequency of this positive superhumps  $F_{\text{sh}}$  and the frequency of the known



**Fig. 7.** Above: PDM for the 2002 second wide outburst superoutburst (BJD 2452495–BJD 2452499). The 90% confidence interval for  $\theta$  is shown by green strip. The preferable period is marked. Below: The average light curve for the 0.1049 d period. For clarity data are reproduced twice.

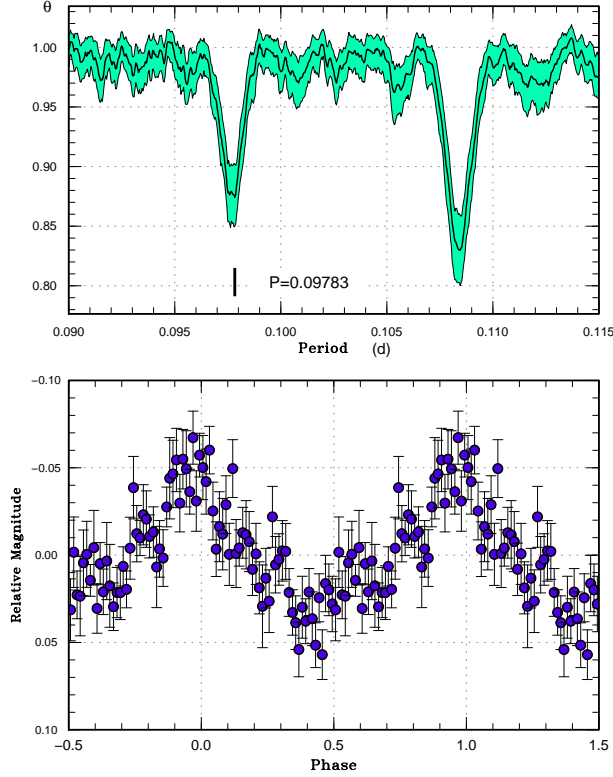
orbital period  $F_{\text{orb}}$ , we obtain the fractional period excess (in the frequency unit)  $\epsilon^* = 1 - F_{\text{sh}}/F_{\text{orb}} = 0.072$ .

### 5.5. Periodicity Outside Superoutburst

In figure 3, selected nightly light curves for quiescent state of NY Ser are shown. One could see the strong brightness variations on a scale of  $\sim 0.1$  d and some low-amplitude oscillations superposed on the light curves. Despite of the same mean brightness, the amplitude of the quiescent light curves is not stable. Thus it reaches 0.4 mag on BJD 2456461 and BJD 2456482, but was only  $\sim 0.2$  mag on BJD 2456483. Prominent flickering with amplitudes up to 0.1–0.2 mag was superposed on some quiescent light curve.

The figure 4 displays the nightly light curves for the eighth normal outburst in figure 2 when it approached from the maximum to quiescence. In magnitude unit, the amplitude of brightness modulation gradually increases from  $\sim 0.05$  mag to  $\sim 0.4$  mag over the outburst decline. The shape of the light curves during the top of the outburst and the middle of decline is rather structured.

We searched for periodicity of the observations in 2013 of NY Ser in the state outside the superoutburst. Taking into account that before the superoutburst NY Ser was in a state



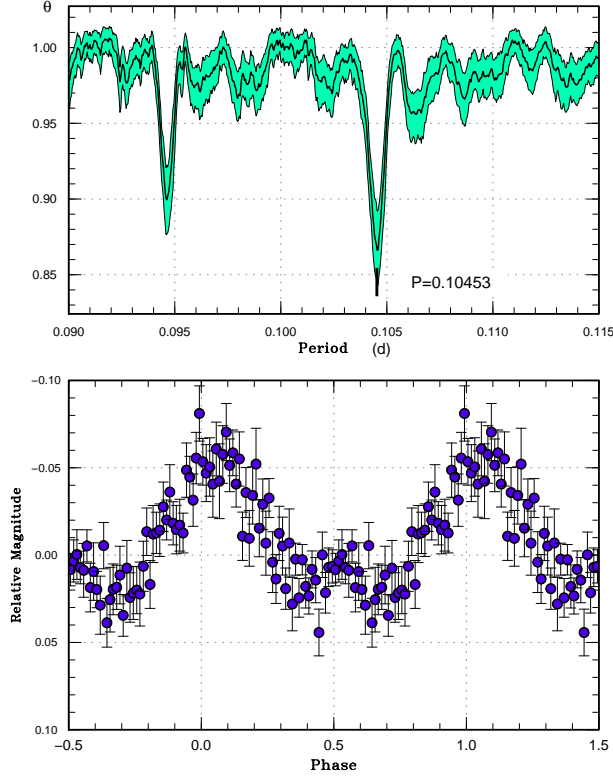
**Fig. 8.** Above: PDM analysis for the 2013 first wide outburst. The 90% confidence interval for  $\theta$  is shown by green strip. The preferable period is marked. Below: The phase-averaged light curve for the 0.09783 d period. For clarity data are reproduced twice.

of a less frequent normal outbursts than after the superoutburst, we studied the periodicity for these states separately. The first data set included all the data both in minimum and all normal outbursts before the superoutburst (see figure 10). One could see a sharp strong signal on the periodogram for the first data set pointing to the period of 0.097531(4) d that coincides with the orbital one. One-day alias period at 0.108 d is also presented. The averaged light curve has the amplitude of  $\sim 1$  mag and some dip at a phase around 0.3–0.4.

The second data set included the data of the highest outburst activity, i.e., the fifth and sixth normal outbursts and quiescence around them. The result of PDM analysis is shown in figure 11. This periodogram contains the two strongest signals at the period of 0.10465(12) d and 0.09744(5) d, which we believe to be the period of positive superhumps and the orbital period, respectively.

Our conclusion is that during the state of relatively infrequent outbursts the orbital modulation was the dominant signal both during normal outbursts and in quiescence. During the state of most frequent outbursts we confidently detected the co-existence of the surviving positive superhumps and orbital period.

As mentioned above, after this superoutburst the cycle length of the normal outbursts shortened up to 5 d–6 d. The effect of a change of the normal outburst frequency was detected

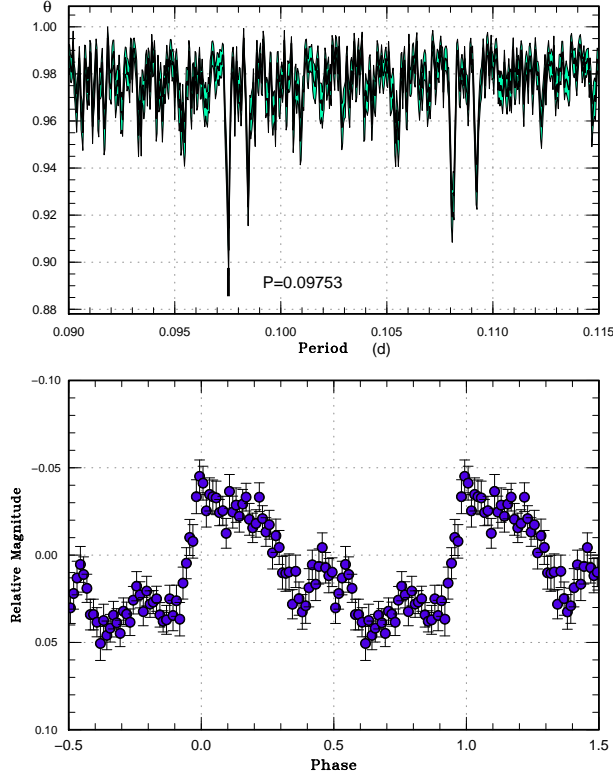


**Fig. 9.** Above: PDM analysis fore the 2013 second wide outburst (superoutburst). The 90% confidence interval for  $\theta$  is shown by green strip. The preferable period is marked. Below: the phase-averaged light curve for the formally best period of 0.10453 d period. For clarity data are reproduced twice.

for several stars. For V1504 Cyg (Osaki, Kato 2013a) and V344 Lyr (Osaki, Kato 2013b) it is established that the decrease of the frequency of normal outbursts is accompanied by the negative superhumps appearance. Vice versa, the disappearing of the negative superhumps was found for V503 Cyg [Kato et al. (2013), Pavlenko et al. (2012)] during the stage of a frequent normal outbursts. Since NY Ser entered the stage of frequent normal outbursts after the 2013 superoutburst, we checked whether there were negative superhumps or “impulsive” negative superhumps [Osaki, Kato (2013b)] in the data in the state of relatively infrequent normal outbursts including the wide outburst.

Using the ratio  $\epsilon_p^*/\epsilon_n^* \sim 7/4$  [Osaki, Kato (2013b)], where the  $\epsilon_p^*$  and the  $\epsilon_n^*$  are 0.067 and 0.038, we obtained the expected period of negative superhumps to be  $\sim 0.09379$  d.

We did not find any indications of negative superhumps neither for the state with relatively infrequent outburst nor for the state with frequent outbursts.



**Fig. 10.** Above: PDM analysis for the all data before 2013 superoutburst. The 90% confidence interval for  $\theta$  is shown by green strip. The preferable period is marked. Below: phase-averaged light curve for the 0.09753 d period. For clarity data are reproduced twice.

## 6. Discussions

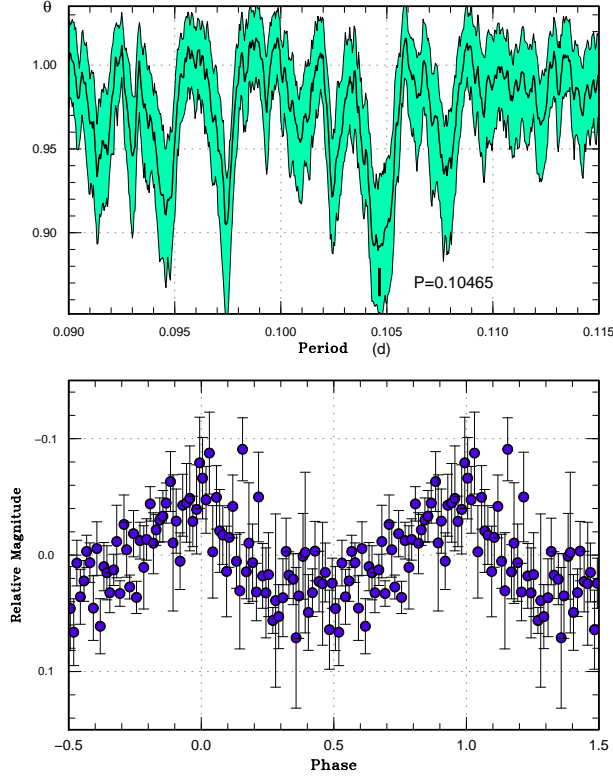
### 6.1. Variation in Long-Term Behavior and Relation to Variation in Outburst Activity

The Catalina Real-time Transient Survey (CRTS; Drake et al. 2009) recorded NY Ser since 2010 May.<sup>2</sup> The quiescent magnitudes of NY Ser before the 2012 season were around 18 mag, while they became brighter (17.0–17.5 mag) in the 2012 and 2013 seasons. This brightening of the quiescent magnitude may suggest an increase in the mass-transfer rate or the increased dissipation in the quiescent disk (e.g. increased quiescent viscosity). Although the cause of such a variation is not clear, this systematic variation in the state of this system may be responsible for the variation in the outburst activity in the last two years.

### 6.2. NY Ser and SU UMa Stars in the Period Gap

NY Ser is a rare, but not unique, binary among the SU UMa-type stars showing some deviation from the bimodality of outbursts. Yet Warner (1995) (and reference therein) mentioned that TU Men, the SU UMa dwarf nova with the longest orbital period within the period gap has trimodal distribution of outburst widths. The longest outbursts were confirmed to be

<sup>2</sup> The public data is available at <http://nesssi.cacr.caltech.edu/DataRelease/>.



**Fig. 11.** Above: PDM analysis for the data after 2013 superoutburst limited to the fifth and sixth normal outbursts and quiescence around them. The 90% confidence interval for  $\theta$  is shown by green strip. The preferable period is marked. Below: the phase-averaged light curve for the 0.10465 d period. Note that it is contaminated by the orbital modulation. For clarity data are reproduced twice.

superoutbursts with a duration of  $\sim 20$  d, the wide outbursts have duration of 8 d and narrow outbursts lasting only for  $\sim 1$  d. Another candidate for an object showing trimodal outbursts is YZ Cnc [Patterson (1979)]. Its period is slightly below the period gap. NY Ser is the first SU UMa dwarf nova possessing much richer diversity of the normal outbursts.

In some respect, the morphology of the outbursts of NY Ser reminds those of CVs above the period gap (having a longer time scale). Note that the novalikes could have the same orbital periods as the dwarf novae, but a higher mass transfer rate. For example, the novalike MV Lyr, located close to the long-period end of the period gap, at some epochs displayed the variety of outbursts looking like an alternation of a sequence “wide outburst — several narrow outbursts” without confirmed superhumps (Pavlenko, Shugarov 1999); (Honeycutt, Kafka 2004).

The existence of the non-magnetic CVs in the period gap is still an open question. According to the theory of magnetic braking (Hameury et al. 1988), when the secondary becomes fully convective, it shrinks and goes within the Roche lobe that happens at  $\sim 3$  hr and fills in it again at  $\sim 2$  hr. According to this most simplest evolutionary scenario, there should be no CV in the period gap. However, according to the Ritter and Kolb catalog (Ritter, Kolb (2003), 7.20 addition) and orbital periods from Pavlenko et al. (2010), Pavlenko et al. (in

**Table 1.** Dwarf Novae In the Gap.

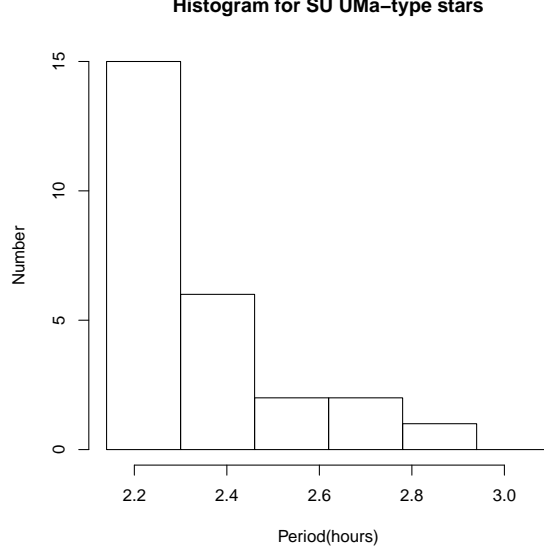
Object Name	Orb.Per (day)*	Type
TU Mensae	0.1172	SU
V405 Vulpeculae	0.1131+	SU
CI Geminorum	0.11+	SU
CS Indi	0.11	DN
AX Capricorni	0.109+	SU
SDSS J162718.39+120435.0	0.104+	SU
CSS1 0531:134052+151341	0.1021	DN
V1239 Herculis	0.1000	SU
MN Draconis	0.100+	SU
OGLE J175310.04-292120.6	0.100+	SU
CSS120813:203938-042908.04	0.100+	SU
V1006 Cygni	0.09904	DN
NY Serpentis	0.0978	SU
DV Scorpii	0.0950+	SU
V444 Pegasi	0.0947+	SU
CSS 110628:142548+151502	0.094+	SU
V725 Aquilae	0.0939+	SU
1RXS J003828.7+250920	0.094511	SU
SBSS 0150+339	0.093+	SU
CSS 110205 J120053-152620	0.093+	SU
CSS 111004:214738+244554	0.0927	SU
AD Mensae	0.0922	SU
TCP J08461690+3115554	0.09138	SU
CSS 080427:131626-151313	0.091+	SU
V589 Herculis	0.0905	SU
GV Piscium	0.090+	SU

\*+ means that the orbital period was  
indirectly determined from the positive superhumps

preparation) for 1RXS J003828.7+250920 [Kato et al. (2012)], there are 26 known dwarf novae in the 2.15–3.18 hr period gap up to the middle of 2013. They are listed in table 1. The majority of them, namely 23 of systems, are SU UMa-type stars. The distribution of the orbital periods of these SU UMa-type stars is presented in figure 12.

One could see that this distribution is not uniform. The number of systems strongly





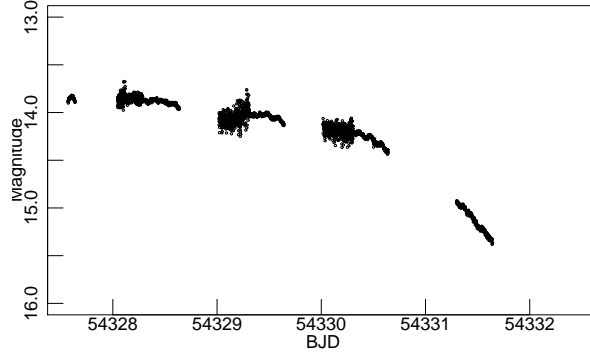
**Fig. 12.** Distribution of the orbital periods of the SU UMa-type stars in the period gap.

increases with shortening of the orbital period. Little more than half of the SU UMa-type stars are concentrated between 2.18 and 2.3 hr. However, this tendency apparently only applies to the distribution of SU UMa stars. According to Knigge (2006) the number of all CVs inside the gap displays the opposite behavior, namely, it increases towards the longer period.

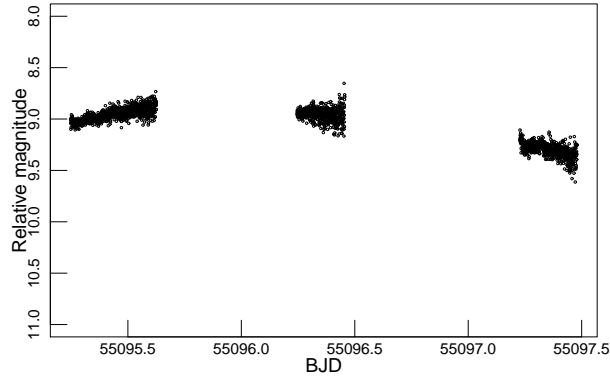
The most accepted explanation of the existence of CVs in the period gap is that they are formed in the period gap (they became contact binaries with the orbital periods just coinciding with periods in the period gap). We here present two explanations why SU UMa-type stars are more concentrated in the shorter periods within the period gap.

If we assume that the SU UMa stars with orbital periods inside the gap are formed uniformly in period, there stars will evolve within the period gap displaying dwarf nova-type activity. It would lead to a higher number of objects in short periods because both objects formed in shorter and longer periods contribute to the short-period population while only the objects formed in longer periods contribute to the long-period population. This effect would resembles accumulation of SU UMa stars at the short period boundary during evolution. This explanation, however, cannot explain why the total number of CVs is larger in region of the longer period in the period gap.

The second, more plausible explanation is that the 3:1 resonance becomes harder to reach for the SU UMa stars with increasing orbital period. Considering that the 3:1 resonance responsible for the superhumps appearing occurs for  $q \leq 0.25$  [Whitehurst (1988), Hirose, Osaki (1990), Lubow (1991)], which condition could be expected to be achieved in dwarf novae closer to the short bound of the period gap. It seems that NY Ser is not able to achieve the 3:1 resonance in some of long outbursts.



**Fig. 13.** The 2007 light curve of V1006 Cyg

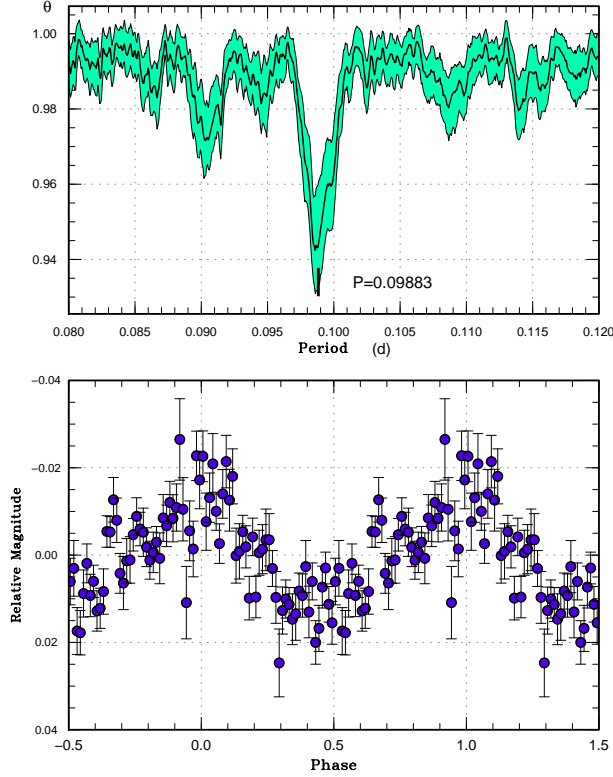


**Fig. 14.** The 2009 light curve of V1006 Cyg

### 6.3. V1006 Cygni Case

According to spectroscopic observations [Sheets et al. (2007)], the orbital period of V1006 Cyg is 0.09903(9) d, qualifying it a dwarf nova in the period gap. In the RK catalog, V1006 Cyg is classified as an SU UMa-type star referring to a preliminary report of a period (vsnet-alert 9487), which was corrected later (vsnet-alert 9489). We here report the result of analysis of this dwarf nova from by VSNET Collaboration [Kato et al. (2004)] obtained in 2007 and 2009 during its long outbursts. The light curves of the 2007 and 2009 outbursts are shown in figures 13 and 14.

The PDM analysis yielded the periods 0.09883(12) d and 0.09892(28) d for the 2007 and 2009 outbursts respectively (see figures 15 and 16), that within the errors coincide with orbital period discovered from spectroscopy. The amplitude of light curve for both outbursts is  $\sim 0.02$  mag. So we found only the orbital modulation in each outburst and there were no indication to the expected superhump period. Since superhumps are not yet detected in V1006 Cyg, we should regard it as an SS Cyg-type star rather than an SU UMa-type star. It is not clear, whether these outbursts represent the wide ones similar to the NY Ser-like wide outbursts with



**Fig. 15.** Above: PDM analysis for the data of V1006 Cyg (2007 outburst). The 90% confidence interval for  $\theta$  is shown by green strip. The preferable period is marked. Below: phase-averaged light curve for the 0.09883 d period. For clarity data are reproduced twice.

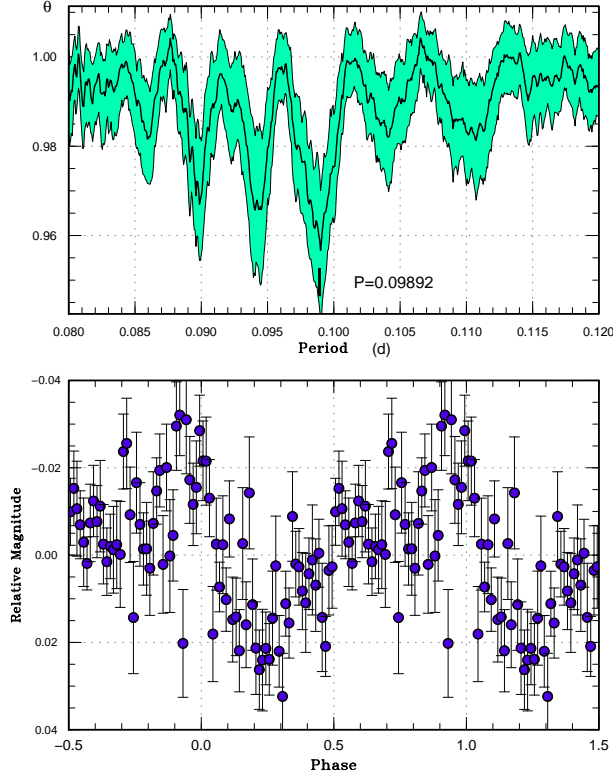
orbital modulation, and, similar to NY Ser or TU Men, one could expect the appearance of superhumps during a much longer outburst. On the other hand, V1006 Cyg would remain a genuine SS Cygni-type star which never reaches the 3:1 resonance. The presence of an apparent SS Cyg-type star having long outbursts without superhumps in the period gap supports our second suggestion that the 3:1 resonance is harder to achieve in longer period in the period gap and it would explain the distribution of SU UMa stars inside the period gap.

## 7. Conclusion

In this work we discovered in NY Ser unusually long 12-d outburst without superhumps but displaying the orbital light variations.

Warner (1995) in his monograph considering the SU UMa-type stars wrote: “if DN are ever found with superoutbursts lacking superhumps they will define a class of their own”. NY Ser could be an example of an intermediate subclass of the dwarf novae possessing some properties of the cataclysmic variables below and above the period gap.

During the state of relatively infrequent outbursts the orbital modulation was the dominant signal both during normal outbursts and in quiescence. During the state of most frequent



**Fig. 16.** Above: PDM analysis for the data of V1006 Cyg (2009 outburst). The 90% confidence interval for  $\theta$  is shown by green strip. The preferable period is marked. Below: phase-averaged light curve for the 0.09892 d period. For clarity data are reproduced twice.

outbursts followed immediately by the 2013 superoutburst, we confidently detected the co-existence of the surviving positive superhumps and orbital period.

We were not able to detect a sufficient number of the superhump maxima during the superoutbursts because of the limited length of nightly light curves, we leave for future the study of evolution of the positive superhumps in this system. We hope that within the future international multi-longitude campaign we could also define the frequency of the appearance of different types of normal outbursts and understand the phenomenon of this unique dwarf nova that could bring us closer to understanding the evolution of CVs inside the period gap.

We are grateful for the suggestions from Prof. Yoji Osaki during the conference “Kyoto Mini-Workshop on Dwarf Novae and Related Systems — New Directions in Time-Series Analysis” in 2013 October. We thank the anonymous referee whose comments greatly improved the paper. This work was supported by the Grant-in-Aid Initiative for High-Dimensional Data-Driven Science through Deepening of Sparse Modeling from the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan. S. Shugarov is grateful for support by the RFBR grant 11-02-00258 (Russia) and VEGA Grant No. 2/0002/13 (Slovakia). K. Antonyuk and N. Pit express a specific acknowledgment to the funding of the CCD Camera FLI ProLine PL230 by Labex OSUG@2020.

**Table 2.** Observation list

JD start*	JD end*	N <sup>†</sup>	Obs <sup>‡</sup>	Exp <sup>§</sup>
52435.3263	52435.3312	2	B	360
52439.3575	52439.4165	14	B	300
52441.3552	52441.3649	3	B	240
52442.3446	52442.4178	25	B	300
52445.3051	52445.418	141	B	60
52446.3496	52446.4398	74	B	90
52447.3253	52447.4467	73	B	120
52448.3293	52448.4421	77	B	120
52449.3179	52449.4399	96	B	90
52450.3542	52450.4862	26	B	360
52451.3588	52451.5138	50	B	240
52453.3394	52453.4962	23	B	240
52454.3737	52454.5166	62	B	180
52455.343	52455.4829	46	B	180
52456.3651	52456.4819	40	B	180
52458.3027	52458.331	9	B	240
52482.308	52482.3371	16	B	120
52483.2906	52483.319	19	B	120
52484.2666	52484.2766	7	B	120
52485.3262	52485.3316	3	B	240
52488.2825	52488.2878	4	B	180
52489.2851	52489.2903	3	B	180
52491.3048	52491.3438	28	B	90
52492.2937	52492.3248	24	B	90
52493.2629	52493.3079	33	B	90
52495.3304	52495.366	18	B	120
52496.2717	52496.3596	44	B	120

\*JD−2456100

<sup>†</sup>Number of observations<sup>‡</sup>A= CrAO/K-380/Apogee E47/Clear;

B=CrAO/K-380/SBIG ST7/Clear; C=CrAO/AZT11/FLI1001E/Clear

D=Tatranska Lomnica/Zeiss600/Apogee U9000/Clear;

E=SAI/Zeiss600/versarray 1300/Clear;

F=CrAO/ZTSh/Apogee E47/R; G=/Chile40cm/FLI16803 CCD/V

<sup>§</sup>Exposure time (sec)

**Table 2.** Observation list(continued)

JD start*	JD end*	N <sup>†</sup>	Obs <sup>‡</sup>	Exp <sup>§</sup>
52497.269	52497.3471	89	B	60
52498.2657	52498.3403	45	B	120
52499.2496	52499.3243	23	B	120
52500.2553	52500.2679	8	B	120
56441.3702	56441.4995	177	A	60
56445.3450	56445.4973	72	A	180
56449.3425	56449.4805	186	A	60
56451.3487	56451.5151	227	A	60
56452.2717	56452.5306	347	A	60
56452.3527	56452.5311	1038	E	30
56453.2942	56453.4279	63	A	180
56454.2817	56454.4716	75	A	180
56454.3144	56454.4189	73	E	60
56455.3054	56455.3073	3	E	60
56455.3216	56455.3641	21	A	180
56457.3087	56457.5093	307	C	60
56461.3803	56461.5152	350	F	30
56461.3883	56461.5013	55	C	180
56462.2901	56462.5301	139	A	120
56463.3134	56463.3317	5	A	180
56466.3195	56466.4122	66	A	120
56467.3698	56467.4349	46	A	120
56469.3442	56469.5135	232	A	60
56470.3058	56470.5177	287	A	60
56471.4078	56471.4791	98	A	60
56472.3177	56472.3954	166	A	30
56473.2826	56473.4284	199	A	60

\*JD−2456100

<sup>†</sup>Number of observations<sup>‡</sup>A= CrAO/K-380/Apogee E47/Clear;

B=CrAO/K-380/SBIG ST7/Clear; C=CrAO/AZT11/FLI1001E/Clear

D=Tatranska Lomnica/Zeiss600/Apogee U9000/Clear;

E=SAI/Zeiss600/versarray 1300/Clear;

F=CrAO/ZTSh/Apogee E47/R; G=/Chile40cm/FLI16803 CCD/V

<sup>§</sup>Exposure time (sec)

**Table 2.** Observation list(continued)

JD start*	JD end*	N <sup>†</sup>	Obs <sup>‡</sup>	Exp <sup>§</sup>
56473.3140	56473.4625	208	A	60
56474.3679	56474.4392	108	A	60
56475.3226	56475.3369	3	D	160
56476.3648	56476.3785	7	D	180
56477.3357	56477.3416	6	D	300
56478.3342	56478.3399	6	D	60
56479.2999	56479.4129	55	C	180
56480.2896	56480.4382	72	C	180
56481.3407	56481.4181	38	C	180
56482.2958	56482.5008	764	F	20
56482.3603	56482.3649	6	D	60
56483.2875	56483.4152	62	E	180
56483.3296	56483.5040	647	F	20
56483.3402	56483.3467	7	D	60
56484.3876	56484.4982	509	F	20
56485.2986	56485.3112	5	A	180
56486.4483	56486.4922	62	C	60
56489.2660	56489.4673	270	C	60
56490.3873	56490.4086	11	A	180
56491.4279	56491.4343	4	A	180
56492.2856	56492.3301	22	A	180
56492.3073	56492.4290	173	C	60
56493.2781	56493.2918	7	A	180
56493.3534	56493.4731	165	C	60
56494.2734	56494.3625	15	A	360
56495.3015	56495.3778	13	A	360
56496.2693	56496.3866	32	A	300

\*JD−2456100

<sup>†</sup>Number of observations<sup>‡</sup>A= CrAO/K-380/Apogee E47/Clear;

B=CrAO/K-380/SBIG ST7/Clear; C=CrAO/AZT11/FLI1001E/Clear

D=Tatranska Lomnica/Zeiss600/Apogee U9000/Clear;

E=SAI/Zeiss600/versarray 1300/Clear;

F=CrAO/ZTSh/Apogee E47/R; G=/Chile40cm/FLI16803 CCD/V

<sup>§</sup>Exposure time (sec)



**Table 2.** Observation list(continued)

JD start*	JD end*	N <sup>†</sup>	Obs <sup>‡</sup>	Exp <sup>§</sup>
56496.5271	56496.5957	33	G	180
56497.2730	56497.4430	233	A	240
56497.4702	56497.5924	61	G	160
56498.3073	56498.4499	60	A	120
56498.3156	56498.4423	176	C	120
56498.4704	56498.5887	82	G	160
56499.3218	56499.4159	48	A	180
56499.3272	56499.3371	15	C	60
56499.5476	56499.5858	19	G	160
56500.2790	56500.3809	48	A	180
56500.3314	56500.4179	121	C	60
56501.3240	56501.3326	6	A	120
56501.4708	56501.5810	52	G	180
56502.3667	56502.3999	16	A	180
56502.4716	56502.5799	53	G	170
56503.2984	56503.3153	7	A	180
56503.4713	56503.5754	50	G	170
56504.3138	56504.4283	53	A	180
56505.2762	56505.3313	27	A	180
56505.2959	56505.3320	51	C	60
56505.5348	56505.5710	19	G	170
56506.3418	56506.3609	10	A	180
56506.4719	56506.5688	47	G	170
56507.2924	56507.3698	24	A	120
56507.3073	56507.3828	55	C	120
56507.4721	56507.5649	45	G	170
56508.3065	56508.4126	51	A	180

\*JD−2456100

<sup>†</sup>Number of observations<sup>‡</sup>A= CrAO/K-380/Apogee E47/Clear;

B=CrAO/K-380/SBIG ST7/Clear; C=CrAO/AZT11/FLI1001E/Clear

D=Tatranska Lomnica/Zeiss600/Apogee U9000/Clear;

E=SAI/Zeiss600/versarray 1300/Clear;

F=CrAO/ZTSh/Apogee E47/R; G=/Chile40cm/FLI16803 CCD/V

<sup>§</sup>Exposure time (sec)

**Table 2.** Observation list(continued)

JD start*	JD end*	N <sup>†</sup>	Obs <sup>‡</sup>	Exp <sup>§</sup>
56508.4721	56508.5628	44	G	170
56509.2565	56509.3647	41	A	180
56510.3063	56510.4042	71	C	120
56510.3064	56510.4043	71	A	180
56511.2908	56511.3705	58	C	120
56512.4752	56512.5492	36	G	170
56515.3177	56515.3223	16	A	120
56516.2508	56516.3989	69	A	180
56517.2959	56517.3616	32	A	180
56518.2611	56518.3778	46	A	180
56519.2503	56519.3904	66	A	180
56520.3158	56520.3879	34	A	180
56521.2745	56521.3823	393	F	20
56522.2437	56522.3745	480	F	20
56523.2494	56523.3608	207	F	20
56524.2486	56524.2888	19	A	180
56524.2671	56524.3205	31	C	180
56525.2406	56525.3445	50	A	180
56526.2532	56526.3596	51	A	180
56526.2629	56526.3456	39	C	180
56527.3087	56527.3450	18	A	180
56528.2516	56528.3321	16	A	180
56528.2811	56528.3447	31	C	180
56530.2516	56530.3258	36	C	180
56530.2784	56530.3399	30	A	180
56531.2930	56531.3502	28	A	180
56532.2522	56532.3158	31	C	180

\*JD−2456100

<sup>†</sup>Number of observations<sup>‡</sup>A= CrAO/K-380/Apogee E47/Clear;

B=CrAO/K-380/SBIG ST7/Clear; C=CrAO/AZT11/FLI1001E/Clear

D=Tatranska Lomnica/Zeiss600/Apogee U9000/Clear;

E=SAI/Zeiss600/versarray 1300/Clear;

F=CrAO/ZTSh/Apogee E47/R; G=/Chile40cm/FLI16803 CCD/V

<sup>§</sup>Exposure time (sec)

**Table 2.** Observation list(continued)

JD start*	JD end*	N <sup>†</sup>	Obs <sup>‡</sup>	Exp <sup>§</sup>
56533.2402	56533.3505	53	A	180
56534.2490	56534.2533	3	C	180
56536.2947	56536.3002	18	A	180
56537.2451	56537.2535	5	C	180

\*JD−2456100

<sup>†</sup>Number of observations<sup>‡</sup>A= CrAO/K-380/Apogee E47/Clear;

B=CrAO/K-380/SBIG ST7/Clear;C=CrAO/AZT11/FLI1001E/Clear

D=Tatranska Lomnica/Zeiss600/Apogee U9000/Clear;

E=SAI/Zeiss600/versarray 1300/Clear;

F=CrAO/ZTSh/Apogee E47/R;G=/Chile40cm/FLI16803 CCD/V

<sup>§</sup>Exposure time (sec)

## References

- Cannizzo, J. K. 1993, in *Accretion Disks in Compact Stellar Systems*, ed. J. C. Wheeler (Singapore: World Scientific Publishing), p. 6
- Cannizzo, J. K., Smale, A. P., Wood, M. A., Still, M. D., & Howell, S. B. 2012, *ApJ*, 747, 117
- Cleveland, W. S. 1979, *J. Amer. Statist. Assoc.*, 74, 829
- Dai, Z.-B., & Qian, S.-B. 2012, *Mem. Soc. Astron. Ital.*, 83, 614
- Drake, A. J., et al. 2009, *ApJ*, 696, 870
- Fernie, J. D. 1989, *PASP*, 101, 225
- Green, R. F., Ferguson, D. H., Liebert, J., & Schmidt, M. 1982, *PASP*, 94, 560
- Green, R. F., Schmidt, M., & Liebert, J. 1986, *ApJS*, 61, 305
- Hameury, J. M., Lasota, J. P., King, A. R., & Ritter, H. 1988, *MNRAS*, 231, 535
- Hellier, C. 2001, *Cataclysmic Variable Stars: How and why they vary* (Berlin: Springer)
- Hirose, M., & Osaki, Y. 1990, *PASJ*, 42, 135
- Honeycutt, R. K., & Kafka, S. 2004, *AJ*, 128, 1279
- Iida, M., Nogami, D., & Kato, T. 1995, *IBVS*, 4208
- Kato, T. 1995, *IBVS*, 4256, 1
- Kato, T., et al. 2013, *PASJ*, 65, 23
- Kato, T., et al. 2014a, *PASJ*, 66, 30
- Kato, T., et al. 2014b, *PASJ*, in press (arXiv/1406.6428)
- Kato, T., et al. 2009, *PASJ*, 61, S395
- Kato, T., et al. 2012, *PASJ*, 64, 21
- Kato, T., et al. 2010, *PASJ*, 62, 1525
- Kato, T., Uemura, M., Ishioka, R., Nogami, D., Kunjaya, C., Baba, H., & Yamaoka, H. 2004, *PASJ*, 56, S1

- Katysheva, N. A., & Pavlenko, E. P. 2003, *Astrophysics*, 46, 114
- Knigge, C. 2006, *MNRAS*, 373, 484
- Kraft, R. P. 1962, *ApJ*, 135, 408
- Lasota, J.-P. 2001, *New Astron. Rev.*, 45, 449
- Lubow, S. H. 1991, *ApJ*, 381, 259
- Nogami, D., Kato, T., Baba, H., & Masuda, S. 1998, *PASJ*, 50, L1
- Osaki, Y. 1996, *PASP*, 108, 39
- Osaki, Y., & Kato, T. 2013a, *PASJ*, 65, 50
- Osaki, Y., & Kato, T. 2013b, *PASJ*, 65, 95
- Patterson, J. 1979, *AJ*, 84, 804
- Patterson, J., et al. 2003, *PASP*, 115, 1308
- Pavlenko, E. P., Samsonov, D. A., Antonyuk, O. I., Andreev, M. V., Baklanov, A. V., & Sosnovskij, A. A. 2012, *Astrophysics*, 55, 494
- Pavlenko, E. P., & Shugarov, S. Yu. 1999, *A&A*, 343, 909
- Pavlenko, E. P., et al. 2010, *Astron. Rep.*, 54, 6
- Ritter, H., & Kolb, U. 2003, *A&A*, 404, 301
- Romano, G. 1964, *Mem. Soc. Astron. Ital.*, 35, 101
- Schmidtobreick, L., & Tappert, C. 2006, *A&A*, 455, 255
- Sheets, H. A., Thorstensen, J. R., Peters, C. J., Kapusta, A. B., & Taylor, C. J. 2007, *PASP*, 119, 494
- Skiff, B. A. 2007, *VizieR Online Data Catalog*, 2277
- Stellingwerf, R. F. 1978, *ApJ*, 224, 953
- van Paradijs, J. 1983, *A&A*, 125, L16
- Verbunt, F., & Zwaan, C. 1981, *A&A*, 100, L7
- Warner, B. 1995, *Ap&SS*, 226, 187
- Whitehurst, R. 1988, *MNRAS*, 232, 35